5. Major Activities

The previous section summarized the variety of activities that occupy the Laboratory for Atmospheres. This section will expand upon the themes presented previously and provide a more in-depth look at major activities underway in the Laboratory.

Measurements

Studies of the atmospheres of our solar system's planets --- including our own --- require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the ground. All instrument systems provide information leading to a basic understanding of the relationship between atmospheric systems and processes, serve as calibration references for satellite instrument validation, or perform both functions.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations, as well. Balloon and airborne platforms let us view such atmospheric processes as precipitation and cloud systems from a high-altitude vantage point but still within the atmosphere. Such platforms serve as a step in the development of spaceborne instruments. Some instruments, such as the cloud lidar and lidar for measuring winds, are being proposed for space missions.

Table V shows the principal instruments that have been built in the Laboratory or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table V also indicates each instrument's deployment --- in space, on aircraft or balloons, or on the ground. Further information on each instrument appears on the pages following Table V.

Table V: Principal Instruments Supporting Scientific Disciplines in the Laboratory for Atmospheres

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation	Planetary Atmospheres/Solar Influences
Space	Total Ozone Mapping Spectrometer-Earth Probes (TOMS-EP)	Shuttle Ozone Limb Sounding Experiment/ Limb Ozone Retrieval Experiment (SOLSE/LORE) (Shuttle) Rayleigh Scattering Attitude Sensor (RSAS) (Shuttle)	IR Spectrometer Imaging Radiometer (ISIR) (Shuttle)	Solar EUV Flux Monitor Cassini Gas Chromatograph/ Mass Spectrometer (GCMS) Cassini Ion and Neutral Mass Spectrometer (INMS) NOZOMI Spectrometer (NMS) Chemical Analysis of Released Gas Experiment (CHARGE) Neutral Gas and Ion Mass Spectrometer (NGIMS) CONTOUR Mission
Aircraft/ Balloons	Large Aperture Scanning Airborne Lidar (LASAL) ER-2 Doppler Radar (EDOP)	Airborne Raman Lidar (ARL) (DC-8)	Visible and IR Lidar (VIRL) (DC-8) Cloud Lidar System (CLS) (ER-2) Tilt Scan CCD Camera (TSCC) (ER-2) Leonardo Airborne Simulator (LAS) (ER-2)	Solar Disk Sextant (SDS) (Balloon)
Ground	Raman Lidar Direct Detection Doppler Wind Lidar (edge technique) Doppler and Polarimetric Radars	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Temperature and Aerosol Lidar Tropospheric Ozone Lidar	Micro Pulse Lidar (MPL) cloud THickness from Offbeam Returns (THOR) Lidar Scanning Microwave Radiometer (SMiR)	

Spacecraft-Based Instruments (Launch dates are in parentheses)

The ***Total Ozone Mapping Spectrometer*** on Earth Probe has provided daily mapping and long-term trend determination of total ozone, surface UV radiation, volcanic SO2, and UV-absorbing aerosols. (1996) For more information, contact Richard McPeters (mcpeters@wrabbit.gsfc.nasa.gov).

The ***Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)*** measured the vertical distribution of ozone in the stratosphere. SOLSE is an imaging spectrometer to measure the mid- to upper- stratosphere limb; LORE is a photometer to measure ozone profiles in the lower stratosphere and upper troposphere. The first flight experiment flew aboard STS 87. (1997) For more information, contact Richard McPeters (mcpeters@wrabbit.gsfc.nasa.gov).

The ***Rayleigh Scattering Attitude Sensor (RSAS)*** is a new technique for measuring atmospheric properties using scattered light from the Earth's limb. The RSAS wavelength was tuned to UV wavelengths to measure Rayleigh scattering profile, which was used to determine instrument pointing; the concept is applicable for low-cost spacecraft attitude sensing. The instrument was first flown on the Shuttle (1996) and was the precursor to the SOLSE/LORE flight on STS 87. (1997) For more information, contact Ernest Hilsenrath (hilsen@ssbuv.gsfc.nasa.gov).

The ***Infrared Spectrometer Imaging Radiometer (ISIR)*** for the Space Shuttle will improve infrared techniques and technology for observing Earth's clouds and surface from the Space Shuttle in combination with microwave and active optical imaging. ISIR is based on smaller and more reliable IR imaging using uncooled detectors. (1997) For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).

The ***Solar EUV Flux Monitor*** measures the integrated solar Extreme Ultraviolet (EUV) and UV radiation above the Earth's atmosphere. The instrument uses a very small, spherical, windowless photodiode with grids to control the photoelectrons. (2000) For more information, contact Walter Hoegy (hoegy@chapman.gsfc.nasa.gov).

The ***Gas Chromatograph/Mass Spectrometer (GCMS)*** for the Cassini Huygens Probe measured the chemical composition of gases and aerosols in the
atmosphere of Titan. (1997) For more information, contact Hasso Niemann (niemann@pop900.gsfc.nasa.gov).

The ***Ion and Neutral Mass Spectrometer (INMS)*** on Cassini will determine the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of its icy satellites. (1997) For more information, contact Hasso Niemann (niemann@pop900.gsfc.nasa.gov).

The ***Neutral Mass Spectrometer (NMS)*** on Planet-B will measure the composition of the neutral atmosphere of Mars to improve our knowledge and understanding of the energetics, dynamics, and evolution of the Martian atmosphere. The mass spectrometer will be flown on a spacecraft developed by the Japanese Institute of Space and Astronautical Science. (1998) For more information, contact Hasso Niemann (niemann@pop900.gsfc.nasa.gov).

The ***Chemical Analysis of Released Gas Experiment (CHARGE)*** on the Rosetta Mission's Champollion Lander will study the cosmochemical role of comets through chemical and isotopic analysis of cometary ices in a surface lander experiment. Subsurface ices will be collected, vaporized, and chemically analyzed for numerous species by a miniaturized gas chromatograph/mass spectrometer. (2002) For more information, contact Paul Mahaffy (mahaffy@pop900.gsfc.nasa.gov).

The ***Neutral Gas and Ion Mass Spectrometer (NGIMS)*** on the CONTOUR Mission will provide detailed compositional data on both gas and dust in the near-nucleus environment at precisions comparable to those of Giotto or better. For more information, contact Paul Mahaffy (mahaffy@pop900.gsfc.nasa.gov).

Aircraft-Based Instruments

The ***Large Aperture Scanning Airborne Lidar (LASAL)*** measures atmospheric backscatter with an emphasis on boundary-layer height and structure. Capable of (raster) scanning at up to 90 degrees per second, it provides a three-dimensional view of the aerosol structure of the lower troposphere and boundary layer. For more information, contact Stephen Palm (spp@virl.gsfc.nasa.gov).

The ***ER-2 Doppler Radar (EDOP)*** measures the vertical rain and wind structure of precipitation systems to improve our understanding of mesoscale convective system structure. The data are also used to validate spaceborne rain measurement algorithms. For more information, contact Gerald Heymsfield (heymsfield@carmen.gsfc.nasa.gov).

The ***Airborne Raman Lidar (ARL)*** measures the structure and concentration of methane and water vapor in the troposphere and lower stratosphere to further understand the chemistry of this region. For more information, contact Thomas McGee (mcgee@aeolus.gsfc.nasa.gov).

The ***Visible and IR Lidar (VIRL)*** measures aerosol particles and cloud backscatter at multiple wavelengths. The instrument consists of a Nd:YAG at, 0.532, 1.064, 1.54 and 2.16 microns. It operates with a power of 300 MJ at high pulse repetition frequency (50Hz). For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).
The ***Cloud Lidar System (CLS)*** measures cloud and aerosol structure from the high altitude ER-2 aircraft, in combination with multispectral visible, microwave, and infrared imaging radiometers. The data are used in radiation and remote sensing studies. For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).

The ***Tilt Scan CCD Camera (TSCC)*** measures bidirectional reflectance with high spatial and spectral resolution in rapid time sequence for high- and low-altitude clouds. The instrument also measures polarization. The data are used in cloud radiative transfer studies and remote sensing applications For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).

The ***Leonardo Airborne Simulator (LAS)*** is an imaging spectrometer (hyperspectral) with moderate spectral resolutions. LAS will measure reflected solar radiation to retrieve atmospheric properties such as column water vapor amount, aerosol loadings, cloud properties, and surface characteristics. This instrument is currently under development and will be deployed aboard NASA ER-2 during the Southern Africa Fire-Atmosphere Research Initiative (SAFARI) campaign. For more information, contact Si-Chee Tsay (tsay@climate.gsfc.nasa.gov).

Balloon-Based Instruments

The ***Solar Disk Sextant (SDS)*** measures the diameter of the Sun to milli-arc-second accuracy to determine the relationship between the Sun's diameter and the solar constant. For more information, contact Donald Silbert (dsilbert@pop900.gsfc.nasa.gov).

Ground-Based Instruments

Raman Lidar measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction, and their structure in the troposphere. These trailer-based measurements are important for studies of radiative transfer, convection, and the hydrological cycle, as well as for assessing the water and aerosol measurement capabilities of surface-, aircraft-, and satellite-based instruments. For more information, contact Geary Schwemmer (geary@virl.gsfc.nasa.gov).

Direct Detection Doppler Wind Lidar measures vertical wind profile from the surface to 12 km, using the double-edge technique. Doppler measurements are derived from aerosol and molecular backscatter at 1064 nm and 355 nm. For more information, contact Bruce Gentry (gentry@agnes.gsfc.nasa.gov).

Doppler and Polarimetric Radars, supported by specifically developed disdrometers and rain-rate gauges, are the fundamental components of the TRMM validation effort. For more information, contact Otto Thiele (thiele@trmm.gsfc.nasa.gov).
The ***Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE)*** measures vertical profiles of ozone, aerosols, and temperature. The system collects elastically and Raman-scattered returns using Differential Absorption Lidar (DIAL). For more information, contact Thomas McGee (mcgee@aeolus.gsfc.nasa.gov).

The ***Temperature and Aerosol Lidar*** measures vertical profiles of aerosols at wavelengths of 351, 382, 532, and 1064 nm, and measures temperatures down to altitudes of four to five km. For more information, contact Thomas McGee (mcgee@aeolus.gsfc.nasa.gov).

The ***Tropospheric Ozone Lidar*** measures tropospheric ozone at wavelengths that have a large ozone absorption cross section. The system provides validation data for research and development programs aimed at monitoring tropospheric ozone from space. For more information, contact Thomas McGee (mcgee@aeolus.gsfc.nasa.gov).

Micro Pulse Lidar (MPL) makes quantitative measurements of clouds and aerosols. MPL is a unique eye-safe lidar system that operates continuously (24 hours a day) in an autonomous fashion. Ten instruments are currently deployed. For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).

The cloud ***THickness from Offbeam Returns (THOR) Lidar*** will determine the physical and optical thickness of dense cloud layers from the cloud Green's function, which is the halo of diffuse light up to 0.5 km from the entry point of a lidar beam incident on the cloud layer. Lidar returns at these wide angles are stonger for thicker clouds and are relatively insensitive to cloud microphysics. (2001). For more information, contact Robert Cahalan (cahalan@clouds.gsfc.nasa.gov).

The ***Scanning Microwave Radiometer (SMiR)*** will measure the column amounts of water vapor and cloud liquid water using discrete microwave frequencies. This instrument will be deployed to the upcoming series of SAFARI campaigns. For more information, contact Si-Chee Tsay (tsay@climate.gsfc.nasa.gov).

Field Campaigns

Field campaigns typically use the resources of NASA, other agencies, and other countries to carry out scientific experiments or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2 and DC-8, serve as platforms from which remote sensing observations are made. Ground systems are also used for soundings and *in situ* measurements. In 1998, Laboratory personnel supported many such activities as scientific investigators or as mission participants in the planning and coordination phases. Field campaigns supported in this way include the following:

The ***Atmospheric Radiation Measurement Program (ARM)*** is a Department of Energy (DOE) program in which NASA participates. ARM is organized to study shortwave and longwave radiation, and cloud physics and dynamics. The program aims to determine how cloud structure is related to cloud albedo, transmission, and cloud absorption. ARM will also study the influence of all these factors on GCM. For more information, contact James Spinhirne (jspin@virl.gsfc.nasa.gov).

The ***Network for the Detection of Stratospheric Change (NDSC)*****,** is an international program to determine changes in the physical and chemical state of the stratosphere, to obtain data to test and improve multidimensional stratospheric chemical and dynamical models, and to provide independent calibration of satellite instruments. For more information, contact Thomas McGee (mcgee@aeolus.gsfc.nasa.gov).

Photochemistry of Ozone Loss in the Arctic Region in Summer (POLARIS) has the scientific objective of evaluating the reduction of stratospheric ozone over a range of altitudes and latitudes in summer in the Northern Hemisphere. The results will contribute to an assessment of the atmospheric effects of aviation emissions of gases and particles. For more information, contact Paul Newman (newman@notus.gsfc.nasa.gov).

The ***Subsonic Assessment (SASS) Ozone and Nitrogen Oxides Experiment (SONEX)*** studies the climatology of upper-tropospheric/lower-stratospheric NO_x, O_3, and other ozone precursors and tracers in the North Atlantic. The experiment includes latitudinal gradients to allow monitoring of these constitutents in regions of high and low air traffic and high and low continental influence. For more information, contact Stephan Kawa (kawa@maia.gsfc.nasa.gov).

Stratosphere Tracers of Atmospheric Transport (STRAT) has the primary goal of measuring the morphology of long-lived tracers and dynamical quantities as functions of altitude, latitude, and season. These measurements will help us predict global-scale transport distribution of high-speed civil transport (HSCT) exhaust in the lower stratosphere. For more information, contact Paul Newman (newman@notus.gsfc.nasa.gov).

South China Sea Monsoon Experiment (SCSMEX) is an international field experiment to study the water and energy cycles of the Asian monsoon regions. The purpose of the experiment is to better understand the key physical processes in the onset, maintenance, and variability of the monsoon over southeast Asia and southern China. This understanding is expected to lead to improved forecasts of the monsoon. For more information, contact William Lau (lau@climate.gsfc.nasa.gov).

Data Products and Data Analysis

Once the raw binary data have been obtained from the instruments, they must be converted to a format that makes them comprehensible to humans and amenable to interpretation. After decommutating housekeeping and other supporting data, Laboratory scientists use algorithms to generate data sets for weather, climate, and global change research.

Data Sets for Climate Research

Televised Infrared Operational Satellite (TIROS) Operational Vertical Sounder Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multi-year climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is the TIROS Operational Vertical Sounder (TOVS). TOVS is comprised of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Special Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We're now reprocessing TOVS data from 1979 to the present, using an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations. The data are used to study global and regional natural variability and trends between surface and atmospheric anomalies. Data has been processed for the period 1985 to the present. Real time processing began in August 1997 to study the 1997 El Niño. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

Aerosol Products from the Total Ozone Mapping Spectrometer

Laboratory scientists are generating a unique new data set of atmospheric aerosols by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by the TOMS. Laboratory staff developed the technique for extracting aerosol information from ultraviolet in 1996. This technique differs from others in that the ultraviolet measurements can reliably separate UV absorbing aerosols (such as desert dust and smoke from biomass burning) from non-absorbing aerosols (such as sulfates, sea-salt, and ground-level fog). In addition, the UV technique can measure aerosols over land and can detect some types of aerosols over snow/ice and clouds.

TOMS aerosol data are currently available in the form of an (uncalibrated) index, which, nevertheless, is providing excellent information about sources, transport, and seasonal variation of a variety of aerosol types. Work is currently in progress to relate the index to aerosol optical thickness and single-scatter albedo. For more information, contact Jay Herman (herman@tparty.gsfc.nasa.gov).

Global Precipitation Data Set

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing intra- and inter-annual climatic fluctuations on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory have led the GPCP effort to merge microwave data from low-Earth-orbit satellites, infrared data from geostationary orbit satellites, and data from ground-based rain gauges to produce the best estimates of global precipitation.

The currently released data set, the GPCP Version 1a Combined Precipitation Data Set, provides global, monthly precipitation estimates for the period July 1987 to the present. Updates are being produced on a quarterly basis. The release totals 19 products, including the single-source input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at World Data Center A (located at the National Climatic Data Center in Asheville, NC), at the Goddard Distributed Active Archive Center (DAAC), and at the Global Precipitation Climatology Centre (located at the Deutscher Wetterdienst in Offenbach, Germany). For more information, contact Robert Adler (adler@agnes.gsfc.nasa.gov).

Atmospheric Ozone Research

Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, and human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

With the anticipated growth in air travel in the next few years, another area of important research underway in the Laboratory is aimed at understanding the effects of aircraft emissions on the atmosphere's chemistry and physics. For more information, contact Pawan K. Bhartia (bhartia@chapman.gsfc.nasa.gov).

Total Column Ozone and Vertical Profile

The Clean Air Act Amendment of 1977 assigned NASA major responsibility for studying the ozone layer. Laboratory for Atmospheres scientists have been involved in this activity since the late 1960s when a satellite instrumentthe Backscatter Ultraviolet (BUV) Spectrometerwas launched on NASA's Nimbus-4 satellite to measure the column amount and vertical distribution of ozone. These measurements are continuing aboard several follow-on missions launched by NASA, NOAA, and, more recently, by the European Space Agency.

An important activity in the Laboratory is developing a high-quality, long-term ozone record from these satellite sensors and comparing that record with ground-based and other satellite sensors. This effortalready more than a quarter century in durationhas produced ozone data sets that have played a key role in identifying the global loss of ozone due to certain human-made chemicals. This knowledge has contributed to international agreements to phase out these chemicals by the end of this century. For more information, contact Pawan K. Bhartia (bhartia@chapman.gsfc.nasa.gov).

Surface UV Flux

The primary reason for measuring atmospheric ozone is to understand how the UV flux at the surface might be changing and how this change might effect the biosphere.

The sensitivity of the surface UV flux to ozone changes can be calculated by using atmospheric models. Yet, until recently, we had no rigorous test of these models, particularly in the presence of aerosols and clouds. By comparing a multi-year data set of surface UV flux generated from TOMS data and high-quality ground-based measurements, we are increasingly able to quantify the respective roles of ozone, aerosols, and clouds in controlling the surface UV flux over the globe. For more information, contact Jay Herman (herman@tparty.gsfc.nasa.gov).

Rain Measurement Validation for the TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable area- and time-averaged rainfall data from numerous representative tropical and sub-tropical sites world wide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites will be available via the TRMM Science Data and Information System (TSDIS). The list of data products has been developed to cover a range of space and time scales that will adequately reflect the rainfall variability and sampling characteristics of the TRMM Observatory. With these products, the validity of TRMM measurements will be established with accuracies that meet mission requirements.

During the pre-mission phase, the emphasis was on rain measurement research, precipitation physics, development of measurement and procedural techniques for calibrating the mission GV sites, development of algorithms and software for generation of standardized products, provision of operational software to TSDIS, and establishment of long-term climatological rainfall data bases.

With essential elements of the pre-mission phase continuing, the post-launch emphasis in 1998 and beyond is on field campaigns to improve TRMM algorithms, cloud models, and to provide high-resolution validation data. During the year, campaigns were conducted in Texas and Florida (TEFLUN-A and -B) to provide TRMM underflights with ER-2 equipped with instrumentation similar to TRMM and supported with ground radars, profilers, and other instrumentation. Also, during the year, radars on a ship and island were deployed with the South China Sea Monsoon Experiment (SCSMEX) to provide oceanic validation data. An intensive effort during the year was directed toward the implementation of a major over land field campaign in January and February 1999 at Rondonia, Brazil. Also, documentation was developed for a major over ocean campaign to be conducted in July, August, and September 1999 at Kwajalein Atoll, RMI. For more information, contact Christian Kummerow (kummerow@audry.gsfc.nasa.gov).

Data Assimilation

The Data Assimilation Office (DAO) in the Laboratory has taken on the challenge of providing to the research community a coherent, global, near-real-time picture of the evolving Earth system. The DAO is developing a state-of-the-art data assimilation system (DAS) to extract the usable information available from a vast number of observations of the Earth system's many components, including the atmosphere, the oceans, the Earth's land surfaces, the biosphere, and the cryosphere (ice sheets over land or sea).

The DAS is made of several components including an atmospheric prediction model, a statistical analysis scheme, and models to diagnose unobservable quantities. Each of these components requires intense research, development, and testing. Much attention must be given to insuring that the components interact properly with one another to produce meaningful, research-quality data sets for the Earth-system-science research community.

Development of the Data Assimilation System

The first version of the DAO system, known as the GEOS-1 DAS, has been run for the period 1980-1995. Segments of this 16-year reanalysis data set have already been utilized by several hundred investigators, including DAO staff themselves. This data set is available to the research community. Procedures to obtain the data sets and more general information about the DAO may be obtained from the DAO home page (http://dao.gsfc.nasa.gov).

The current GEOS-2 DAS extends its analysis of the atmosphere up through the stratospheric region. The system uses finer vertical resolution and a more accurate and complete package of physical parameterizations in its predictive model. GEOS-2 DAS also employs the recently developed Physical-space Statistical Analysis System (PSAS). The future DAS will also include assimilation of marine surface winds, a representation of cloud-liquid water, sophisticated representation of the land surfaces of the Earth, improved retrievals of moisture and temperature, an adaptive representation of error covariances, and more sophisticated quality control of observations. For more information, contact Robert Atlas (ratlas@dao.gsfc.nasa.gov).

Observing System Simulation Experiments

Since the advent of meteorological satellites in the 1960s, considerable research effort has been directed toward designing space-borne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction. Observing system simulation experiments (OSSEs) have played an important role in this research. Such studies have helped in designing the global observing system, testing different methods of assimilating satellite data, and assessing the potential impact of satellite data on weather forecasting.

At the present time, OSSEs are being conducted to (1) provide a quantitative assessment of the potential impact of currently proposed space-based observing systems on global change research, (2) evaluate new methodology for assimilating specific observing systems, and (3) evaluate tradeoffs in the design and configuration of these observing systems. For more information, contact Robert Atlas (ratlas@dao.gsfc.nasa.gov).

Data Analysis

Seasonal-to-Interannual Variability and Prediction

Climate research seeks to identify natural variability on seasonal, inter-annual, and inter-decadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model outputs, and assimilated data. Climate diagnostic studies will be combined with modeling studies to unravel physical processes underpinning seasonal-to-interannual variability. The key areas of research include the El Niño Southern Oscillation (ENSO), monsoon variability, interseasonal oscillation, and water vapor and cloud feedback processes. Several advanced analytical techniques are used, including wavelets, multivariate empirical orthogonal functions, singular value decomposition, and nonlinear system analysis.

The Laboratory is also involved in NASA's Seasonal to Interannual Prediction Project (NSIPP). This collaboration between NASA and outside scientists is developing a system to predict El Niño events by utilizing a combination of satellite and *in situ* data. Satellite measurements of sea-surface heights throughout the tropical Pacific are expected to be a key element of successful seasonal prediction systems.

Promoting the use of satellite data is a top priority. Other important satellite-derived data sets include the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), Special Sensor Microwave/Imager (SSM/I), MSU, and TOVS Pathfinder data. Data from TRMM and EOS AM and PM platforms will be used extensively, as they become available. For more information, contact William Lau (lau@climate.gsfc.nasa.gov).

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the Advanced Microwave Scanning Radiometer (AMSR) on EOS-PM.

The retrieval techniques belong to four categories: (1) physical/empirical relationships that exist between microwave measurements (active and passive) and rain rates; (2) a theoretical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface; (3) an empirical relationship that exists between cloud thickness and rain rates, using TOVS sounding retrievals; and (4) an analysis technique that uses low-orbit microwave, geosynchronous infrared, and rain gauge information to provide a merged, global precipitation analysis.

The multifrequency technique (category 2) also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations. For more information, contact Robert Adler (adler@agnes.gsfc.nasa.gov).

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei. These nuclei produce different drop size distributions in clouds, which, in turn, will affect the radiative balance of the atmosphere.

Algorithms are being developed to routinely derive aerosol loading optical properties and total precipitable water vapor data products from data to be obtained by the EOS-era Moderate Resolution Imaging Spectroradiometer (MODIS). These algorithms are based on Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), MODIS Airborne simulator, AVHRR, and Landsat Thematic Mapper (TM) data.

Laboratory scientists are actively involved in analyzing data recently obtained from national and international campaigns. These campaigns include Smoke Cloud And Radiation-Brazil (SCAR-B), the SUbsonic aircraft: Contrails and Cloud Effects Special Study (SUCCESS), and the Tropospheric Aerosol Radiative Forcing Observational eXperiment (TARFOX). For more information, contact Yoram Kaufman (kaufman@climate.gsfc.nasa.gov).

Hydrologic Processes and Radiation Studies

Laboratory scientists are developing methods to estimate atmospheric water and energy budgets. These methods include calculating the radiative effects of absorption, emission, and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. The observational data include the ERBE radiation budgets, ISCCP clouds data, Geostationary Meteorological Satellite (GMS; Japan) radiances, National Center for Environmental Prediction (NCEP) sea surface temperature, and Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) observations. The models include the Goddard Earth Observing System (GEOS) GCM, the Goddard Cloud Ensemble model (GCE), and an ocean mixed layer model.

Laboratory scientists study the response of radiation budgets to changes in water vapor and clouds during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. We also investigate the relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature. In addition, we use the GMS radiances to study the upper tropospheric water vapor and its relation to monsoon circulation. For more information, contact William Lau (lau@climate.gsfc.nasa.gov).

Earth Observing System Interdisciplinary Investigations

The overall goal of NASA's Earth Observing System (EOS) Program is to determine the extent, causes, and regional consequences of global climate change. This major scientific challenge will be addressed by more than 20 instruments flown on a series of spacecraft over a period of at least 15 years. In addition to the scientific investigations to be carried out by the instrument scientists, the EOS program also supports various interdisciplinary science investigations. Interdisciplinary investigations, such as the two described below, are designed to improve understanding of the Earth as a system by developing and refining integrated models that will use observations from EOS instruments.

End-to-End Regional Climate Simulation and Prediction System

The End-to-end Regional Climate Simulation and Prediction System activity has three goals: (1) to develop an end-to-end simulation/prediction system to provide better understanding of physical processes in regional land-atmosphere interactions, (2) to enable experimental prediction of regional climate variability, and (3) to provide special land surface and atmosphere data sets to validate satellite algorithms and model results.

The end-to-end system consists of five components: a nested mesoscale model, a coupled land surface model (LSM), a regional four-dimensional data assimilation (4DDA) component, a GCM component, and a macro-hydrologic model. The investigation will provide telescopic downscaling of climate forcings obtained from GCM and from observations. We'll use the results for subcontinental to river-basin scale climate simulation and prediction through the nested Mesoscale Model version 5 (MM5) LSM and the macro-hydrology models. Initial emphases are on the Asian monsoon region, in conjunction with upcoming field campaigns; i.e., the GEWEX Asian Monsoon Experiment (GAME) and SCSMEX. We can apply the system to other regions, such as the GEWEX Continental-Scale International Project (GCIP) and Large-Scale Atmosphere-Biosphere Experiment in Amazonia (LBA). For more information, contact William Lau (lau@climate.gsfc.nasa.gov).

Stratospheric Chemistry and Dynamics

The goal of Laboratory investigations of stratospheric chemistry and dynamics is to separate natural from human-made changes in the Earth's atmosphere, to determine their effects on ozone, and to assess radiative and dynamical feedbacks. We do this by analyzing stratospheric chemical and dynamical observations from current satellites and from aircraft campaigns. Studies include examining the processes that produce the Antarctic ozone hole and evaluating the interannual differences in the amount of ozone lost. The investigation combines Upper Atmosphere Research Satellite (UARS) data, trajectory modeling, and TOMS observations. This work will continue as new instruments are deployed on aircraft and satellites by the United States and by other nations. For more information, contact Mark Schoeberl (schom@zephyr.gsfc.nasa.gov).

Effects of Aircraft on the Atmosphere

Atmospheric Effects of Aviation Project

The Atmospheric Effects of Aviation Project (AEAP) sponsors research to evaluate the impact current subsonic and proposed high-speed civil aircraft have on stratospheric and tropospheric ozone and climate. AEAP is funded by the Office of Aeronautics and Space Transportation Technology. The project operates in coordination with observational and theoretical programs in NASA's Earth Science Enterprise. Elements of this program include aircraft campaigns, modeling of photochemistry and transport, and modeling of cloud-radiation interactions. Recent aircraft campaigns will help us understand the declining summertime portion of the stratospheric ozone annual cycle.

Modeling within the AEAP is concentrated in the Global Modeling Initiative (GMI). The GMI is a multi-institutional effort that is assembling various contributed software modules to create a coupled chemical-transport model, with a shared code residing at Lawrence Livermore National Laboratory. All contributors analyze model output, including members of the Atmospheric Chemistry and Dynamics Branch. The model will be used for three-dimensional aircraft assessment calculations.

The Atmospheric Chemistry and Dynamics Branch also provides the project scientist and several principal investigators to the AEAP, which is managed by the Goddard Flight Projects Directorate, Code 400. For more information, contact Stephan Kawa (kawa@maia.gsfc.nasa.gov).

Modeling

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, we must couple the atmospheric GCM with ocean and land-surface models. Much of the work in this area is conducted in collaboration with Goddard's Laboratory for Hydrospheric Processes, Code 970. The ocean models predict the global ocean circulation --- including the sea surface temperature (SST) --- when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation; transpiration through plants; infiltration; runoff; accumulation, sublimation, and melt of snow and ice; and groundwater budgets.

One of the main objectives of coupled models is forecasting seasonal-to-interannual anomalies such as the El Niño phenomenon. Laboratory scientists are involved in NASA's Seasonal to Interannual Prediction Project (NSIPP), recently established in Goddard's Laboratory for Hydrospheric Processes. NSIPP's main goal is to develop a system capable of assimilating hydrologic data and using that data with complex, coupled ocean-atmosphere models to predict tropical SST with lead times of 6-14 months. A second goal is to use the predicted SST in conjunction with coupled atmosphere-land models to predict changes in global weather patterns. For more information, contact Max Suarez (Max.J.Suarez.1@gsfc.nasa.gov).

Regional Climate Modeling

The core regional climate model (RCM) used for regional climate modeling in the Laboratory is derived from the National Center for Atmospheric Research (NCAR)/Pennsylvania State University MM5 mesoscale model.
The MM5 is a non-hydrostatic meso-alpha- (200-2000km) and meso-beta- (20-200 km) scale primitive equation model. MM5 is an excellent tool for studying the multi-scale dynamics associated with precipitation processes and their impact on regional hydrological cycles. Improved physics include microphysical processes, radiation, land-soil-vegetation, and ocean mixed-layer processes. These variables have been incorporated to produce realistic simulations of tropical-midlatitude precipitation systems and their relationship to the large scale environment. Components of the physical package have been tested for various mesoscale convective systems, including monsoon depressions, supercloud clusters, and meso-scale convective complexes. In an effort to develop an end-to-end RCM, the MM5 has been coupled with the LSM, the Parameterization for Land Atmosphere Cloud Exchange (PLACE) model. The MM5-LSM will be nested within the GEOS GCM over continental scale regions such as Southeast Asia, continental United States, or the Amazon region.

This approach represents a new Laboratory effort geared toward regional climate data analysis and modeling studies, performed in response to the emphasis on regional climate assessment under the Earth Science strategic plan and the science priorities of the US Global Change Research Program (USGCRP). For more information, contact William Lau (lau@climate.gsfc.nasa.gov).

Cloud and Mesoscale Modeling

The MM5 and the cloud resolving Goddard Cloud Ensemble model (GCE) are used in several cloud and mesoscale studies.

These studies include the investigations of the dynamic and thermodynamic processes associated with cyclones and frontal rainbands, surface (ocean, land, and soil) effects on atmospheric convection, cloud-chemistry interactions, tropical and midlatitude convective systems, and stratospheric-tropospheric interaction. Other applications include investigating the effects of assimilating satellite-derived water vapor and precipitation fields on tropical and extra-tropical regional-scale (i.e., hurricanes, cyclones) weather simulations.

Other areas addressed with these models include climate applications involving long-term integrations. These allow the study of air-sea interactions and their application to the cloud-climate feedback mechanisms; and surface energy, radiation, diabatic heating and water budgets associated with tropical and mid-latitude weather systems.

Such models also are used to develop retrieval algorithms. For example, the GCE model is providing TRMM investigators with four-dimensional data sets for the developing and improving TRMM rainfall and heating retrieval algorithms. For more information, contact Wei-Kuo Tao (tao@carmen.gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of physical parameterization and sub-models of the physical climate system is an integral part of climate modeling activities. Laboratory scientists are actively involved in developing and improving physical parameterizations of the major radiative transfer and moisture processes in the atmosphere. Both areas are extremely important for better understanding the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

For atmospheric hydrologic processes, we are developing a new prognostic cloud liquid water scheme, which includes representation of source and sink terms as well as horizontal and vertical advection. This scheme incorporates attributes from physically based cloud life cycles, including the effects of downdraft, full-cloud microphysics within convective towers and anvils, cloud-radiation interactions, cloud microphysics, and cloud inhomogeneity correction. We are testing both the radiation and the prognostic water schemes with *in situ* observations from the Atmospheric Radiation Measurement (ARM) and TOGA-COARE activities. For land-surface processes a new and improved snow physics package is being developed to better simulate the hydrologic cycle. These schemes are being incorporated into the latest version of the GEOS model. For more information, contact Arthur Hou (ahou@dao.gsfc.nasa.gov).

Trace Gas Modeling

We have developed two- and three-dimensional models to understand the behavior of ozone and other atmospheric constituents. We use the two-dimensional models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, and human effects, such as changes in CFCs, nitrogen oxides, and hydrocarbons. The three-dimensional models start with assimilated wind and other meteorological data generated by the DAO and apply chemistry and transport models to simulate short-term variations in ozone and other constituents seen in the measurements. Our goal is to improve our understanding of the complex chemical and dynamical processes that control the ozone layer.

The modeling effort has evolved in four directions: (1) *Lagrangian models* are closely coupled to the trajectory models of an air parcel. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations, (2) *Two-dimensional (2D) non-interactive models* have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used both in data analysis and multidecadal chemical assessment studies, (3) *Two-dimensional interactive models* have interactive radiation and dynamics routines, and can study the dynamical impact of major chemical changes, (4) *Three-dimensional (3D) models* have a full chemistry package, and use the analyzed wind fields for transport.

We use trace gas data from sensors on the UARS and from various NASA-sponsored aircraft and ground-based campaigns to rigorously test models. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2D and 3D models, are critical to the reliability of these models. For more information, contact Anne Douglass (douglass@persephone.gsfc.nasa.gov).

Support for National Oceanic and Atmospheric Administration Operational Satellites

In the preceding pages, we examined The Laboratory for Atmosphere's work in measurements, data products and data analysis, and modeling. In addition, Goddard supports NOAA's remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists assure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA Solar Backscatter Ultraviolet version 2 (SBUV/2) ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Post-doctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

Laboratory members are actively involved in the National Polar Orbiting Environmental Satellite System (NPOESS) Internal Government Studies (IGS) and support the Integrated Program Office (IPO) Joint Agency Requirements Group (JARG) activities.

Geostationary Operational Environmental Satellites

NASA GSFC project engineering and scientific personnel support NOAA for the GOES operational satellites. GOES supplies images and soundings to study atmospheric processes, such as moisture, winds, clouds, and surface conditions. In particular, GOES observations are used by climate analysts to monitor the diurnal variability of clouds and rainfall and to track the movement of water vapor in the upper troposphere. In addition to high quality imagery, the GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States. These mesoscale soundings are improving NOAA's numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images for regions all over the western hemisphere via the World Wide Web (http://rsd.gsfc.nasa.gov/goes/). For more information, contact Dennis Chesters (chesters@agnes.gsfc.nasa.gov).

Polar Orbiting Environmental Satellites

We're developing and optimizing algorithms for analyzing data from the HIRS-3 and the Advanced Microwave Sounding Unit (AMSU), launched on NOAA K in 1998. HIRS/AMSU data will be used as part of the NASA NOAA K validation study. We plan to do continuous real time analysis thereafter. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

Solar Backscatter Ultraviolet/2

NASA's responsibility is to monitor the pre-launch and post-launch calibration of the SBUV/2 and to develop new algorithms to process ozone more accurately.

Laboratory scientists recently developed an algorithm that was used to reprocess the NOAA 11 SBUV/2 data record, covering the period from January 1989 to the present. The algorithm is designed to increase the accuracy of ozone measurements in the Antarctic ozone hole. The absolute calibration was set through comparison with Shuttle Solar Backscatter Ultraviolet (SSBUV), while the relative calibration was stabilized through January 1993 to within ±2-5% per decade. This SBUV/2 data set was joined with the NASA Solar Backscatter Ultraviolet (SBUV) record to produce a continuous 15-year record of ozone. The resulting trends were reported in the 1994 WMO United Nations Environment Program (UNEP) report. For more information, contact Richard McPeters (mcpeters@wrabbit.gsfc.nasa.gov).

National Polar Orbiting Environmental Satellite System

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board, acting as technical advisors. Laboratory personnel were involved in evaluating proposals for the OMPS (Ozone Mapper and Profiler System) and the Crosstrack Infrared Sounder (CrIS), which is a candidate to accompany an AMSU-like crosstrack microwave sounder. Collaboration with the IPO continues through the Operation Algorithm Teams (OATs), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

For OMPS, studies include technology research and demonstrations for advanced TOMS and for a high-vertical-resolution ozone profiler. In addition, advanced algorithms are being developed to improve profiler and total ozone retrieval accuracies and penetration into the lower stratosphere and upper troposphere. For more information, contact Ernest Hilsenrath (hilsen@ssbuv.gsfc.nasa.gov).

CrIS is a high spectral resolution interferometer infrared sounder with capabilities similar to those of the Atmospheric Infra Red Sounder (AIRS). CrIS will fly with AMSU A and the Humidity Sounder Brazil (HSB) on the EOS PM-1 platform, to be launched in December 2000. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. These data will be used in a pseudo-operational mode by NOAA/NESDIS and NOAA/NCEP. Simulation studies were conducted for the IPO to compare the expected performance of AIRS/AMSU/HSB with that of an earlier version of CrIS, together with AMSU/HSB. The simulations will help in assessing the instruments' relative utility as an advanced sounding system on NOAA N' in 2007 and on the NPOESS converged platform starting in 2011.

Tropospheric wind measurements are the number one priority in the unaccommodated Environmental Data Records (EDRs) identified in the NPOESS Integrated Operational Requirements Document (IORD-1). The Laboratory is using these requirements in developing the Edge Technique Wind Lidar System to measure tropospheric wind profiles on a global scale. The IPO is supporting the effort through their IGS program.

The IPO is also supporting a Goddard design study of a visible and infrared imaging radiometer based on advanced-technology array detectors. The goal is an imaging radiometer smaller, less costly, and more capable than previous instruments. The program is developing an instrument based on advanced microbolometer array (MBA) warm thermal detectors. A prototype MBA-based instrument, the ISIR, flew as a Shuttle small attached payload in August 1997. Its performance as a space-borne imager will be assessed from this Shuttle mission. A design study is planned for an array detector-based, operational, polar-orbiting, visible and infrared imager for a low-Earth-orbiter, applying the results of the ground and flight performance testing of ISIR. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

The IPO supports the development of the Holographic Optical Telescope and Scanner (HOTS) which investigates the feasibility of using this technology for lidar applications on NPOESS, including, but not limited to, a direct detection (edge) wind lidar system. For more information, contact Geary Schwemmer (geary@virl.gsfc.nasa.gov).

Responsible NASA official: Bob Theis